Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Emerging wideband reconfigurable antenna elements for wireless communication systems

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Abstract: This presentation introduces several emerging reconfigurable antenna elements for modern broadband wireless communication systems. Firstly, we present a wideband $\pm 45^0$ linear polarization (LP) reconfigurable antenna with broadside radiation pattern. A new method is proposed to achieve the switchable polarizations by designing a reconfigurable feeding aperture for a square radiating patch. To realize this, we introduce four PIN diodes as RF switches connected between a cross feeding aperture such that the orthogonal direction of the rectangular aperture can be controllable. As the result, $\pm 45^0$ linear polarizations can be reconfigured. Furthermore, in order to widen the operating bandwidth, the stacked patches are adopted. Beside of the linear polarization, we also propose a wideband circular polarization (CP) reconfigurable antenna with uni-directional broadside radiation pattern. The antenna consists of four planar monopolar radiators excited by an output reconfigurable feeding network. Switchable left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP) are realized by controlling the output phases of the feeding network for the monopolar radiators. In addition, we also introduce a wideband omni-directional CP reconfigurable antenna with a conical-beam pattern. The idea is to combine a broadband center-fed monopolar patch working as an electric dipole (E-dipole) and eight reconfigurable coupling loop stub radiators as the magnetic dipoles (M-dipole) together to generate the reconfigurable CP conical-beam radiation. The proposed three wideband reconfigurable antenna designs have overcome the narrowband challenge in traditional polarization reconfigurable antenna designs.

Keywords: reconfigurable antennas, wideband, polarization diversity, aperture-fed patch antenna, conical-beam, monopolar patch.

References:

[1] Z. X. Yang, H. C. Yang, J. S. Hong and Y. Li, “Bandwidth enhancement of a polarization-reconfigurable patch antenna with stair-slots on the ground,” IEEE Antenna and Wireless Propag. Letters, vol. 13, pp. 579-582, 2014.

[2] J. S. Row, W. L. Liu, and T. R. Chen, “Circular polarization and polarization reconfigurable designs for annular slot antennas,” IEEE Trans. Antennas Propag., vol. 60, no.12, pp. 5998-6002, Dec. 2012.

[3] A. Khidre,, K. F. Lee, F. Yang, and A. Z. Elsherbeni, “Circular polarization reconfigurable wideband E-shaped patch antenna for wireless applications,” IEEE Trans. Antennas Propag., vol. 61, no.2, pp. 960-964, Feb., 2013.

[4] K. Boonying, C. Phongcharoenpanich and S. Kosulvit, “Polarization reconfigurable suspended antenna using RF switches and P-I-N diodes,” The 4th Joint International Conference on Information and Communication Technology, 2014.

[5] H. Aïssat, L. Cirio, M. Grzeskowiak, J. M. Laheurte and O. Picon, “Reconfigurable circularly polarized antenna for short-range communication systems,” IEEE Trans. Microw. Theory Tech., vol. 54, no. 6, pp. 2856–2863, June, 2006.

[6] W. Lin and H. Wong, “Wideband circular polarization reconfigurable antenna,” IEEE Trans. Antennas Propag., vol. 63, no. 12, pp. 5938–5944, Dec, 2015.

[7] W. Lin and H. Wong, “Polarization reconfigurable wheel-shaped antenna with conical-beam radiation pattern,” IEEE Trans. Antennas Propag., vol. 63, no. 2, pp. 491–499, Feb, 2015.

Wei LIN was born in Lanzhou, Gansu Province, China. He received the B.E. degree in information engineering and the M.E. degree in electromagnetic field and microwave engineering from South China University and Technology, Guangzhou, China, in 2009 and 2012, respectively. He was working as Research Associate in Nanyang Technological University, Singapore from August 2012 to July 2013. He is currently pursuing his PhD degree at City University of Hong Kong, Hong Kong S. A. R., China. He received the Young Scientist Award at the IEEE Region 10 conference (TENCON) in November 2015. His research interests include antennas, wireless circuits and systems, etc.

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International Symposium on Antennas and Propagation (ISAP2015)

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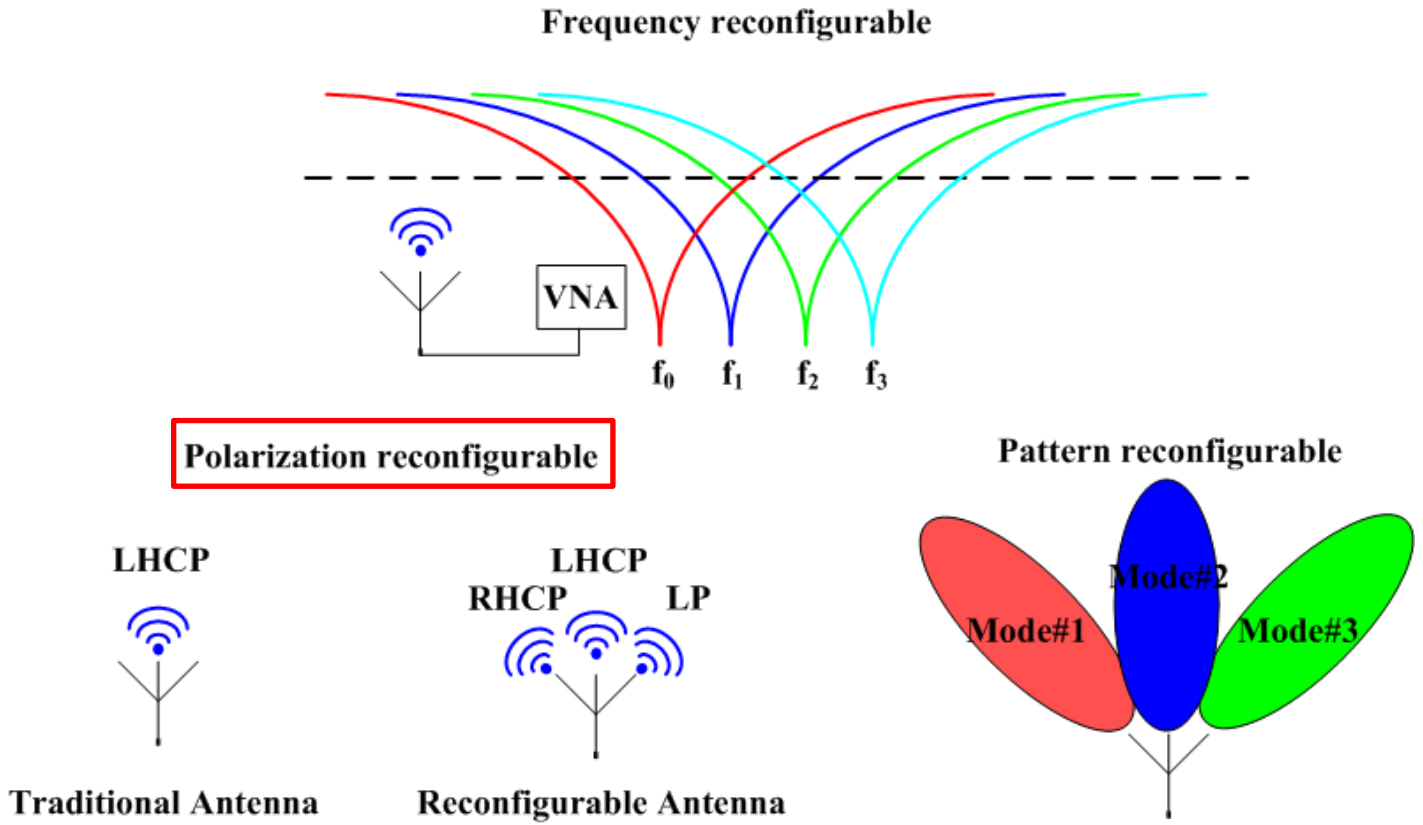
Outline

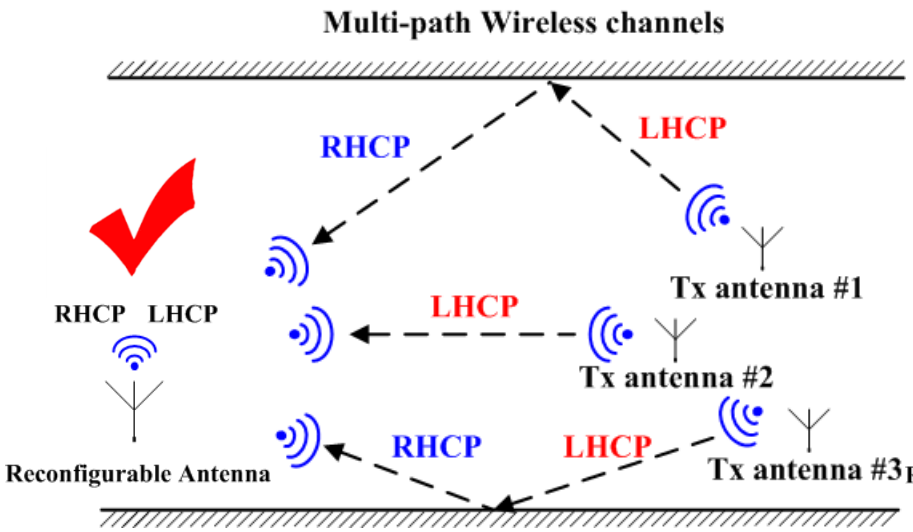
- Introduction to Reconfigurable Antennas
- Wideband $\pm 45^{o}$ Linear Polarization Reconfigurable Antenna with Broadside Radiation Pattern
- Wideband Circular Polarization Reconfigurable Antenna with Broadside Radiation Pattern
- Wideband Circular Polarization Reconfigurable Antenna with Conical-beam Radiation Pattern
- Conclusion

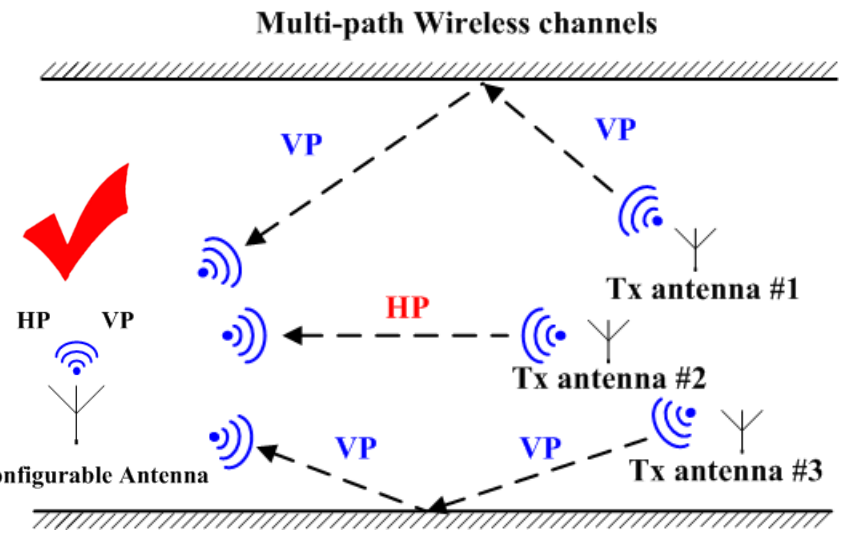
Reconfigurable Antennas



- Adopt RF switches, Varactors, Capacitors and Inductors, etc…
- Enhance the performance of a communication system: multipath interference, channel capacity and polarization coding.

Applications by polarization reconfigurable antennas





- Avoid polarization mismatching
- Apply diversity combining technique
- Enable polarization coding

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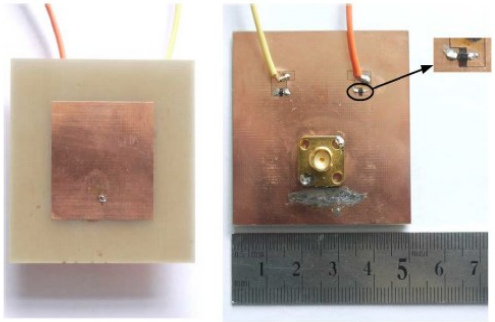
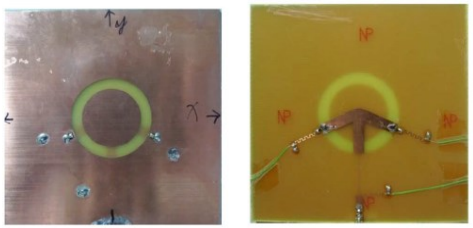
Challenge for circular polarization reconfigurable antennas: Narrow Bandwidth

BW: 1%



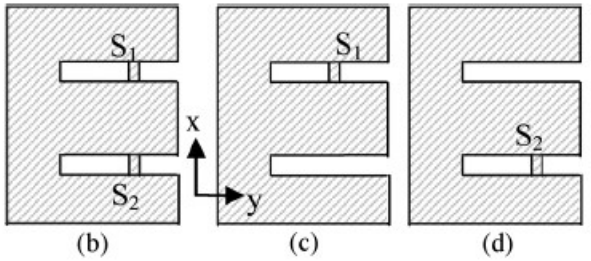
Z. X. Yang, et al., "Bandwidth enhancement of a polarization-reconfigurable patch antenna with stair-slots on the ground," IEEE Antenna and Wireless Propag. Letters, vol. 13, pp. 579-582, 2014.

BW: 4.7%



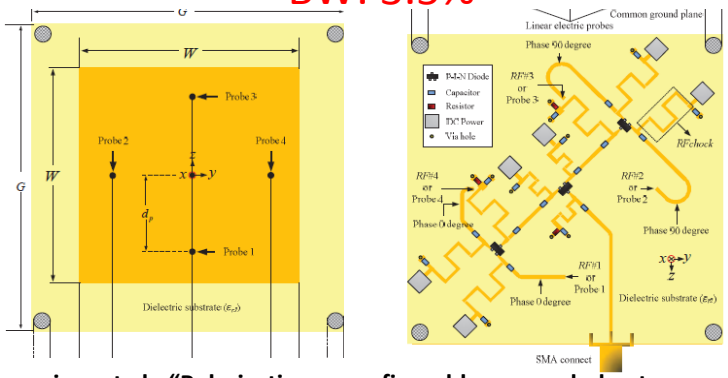
J. S. Row, et al., "Circular polarization and polarization reconfigurable designs for annular slot antennas," IEEE Trans. Antennas Propag., vol. 60, no.12, pp. 5998-6002, Dec. 2012.

BW: 7%



A. Khidre, et al., "Circular polarization reconfigurable wideband E-shaped patch antenna for wireless applications," IEEE Trans. Antennas Propag., vol. 61, no.2, pp. 960-964, Feb., 2013.

BW: 3.5%



K. Boonying, et al., "Polarization reconfigurable suspended antenna using RF switches and P-I-N diodes," The 4th Joint International Conference on Information and Communication Technology, 2014.

BW: 1.8%

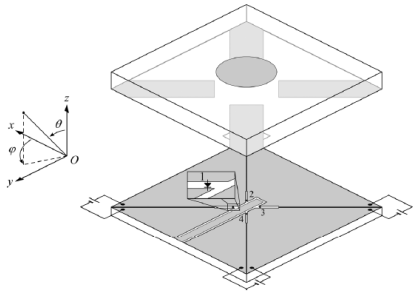


Fig. 12. Circularly polarized reconfigurable structure.

H. Aïssat, et al., "Reconfigurable circularly polarized antenna for short-range communication systems," IEEE Trans. Microw. Theory Tech., vol. 54, no. 6, pp. 2856–2863, June, 2006.

- Reconfigurable radiator or feeding network
- The maximum bandwidth < 10%

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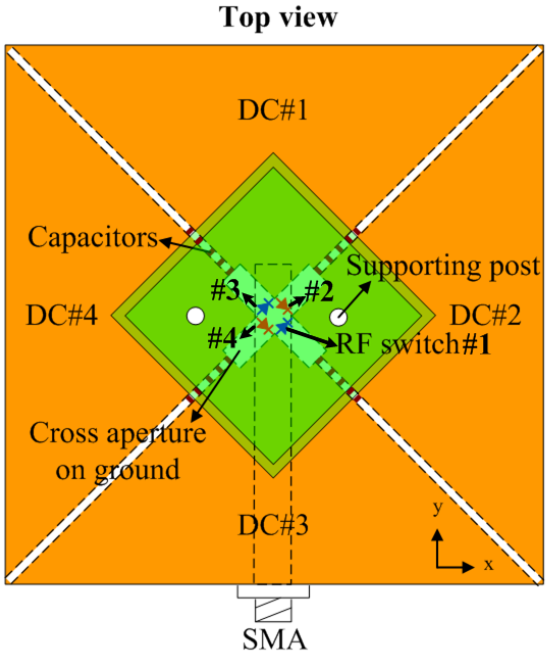
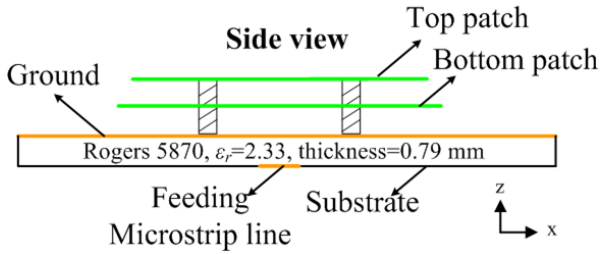
Wideband ±45° Linear Polarization Reconfigurable Antenna





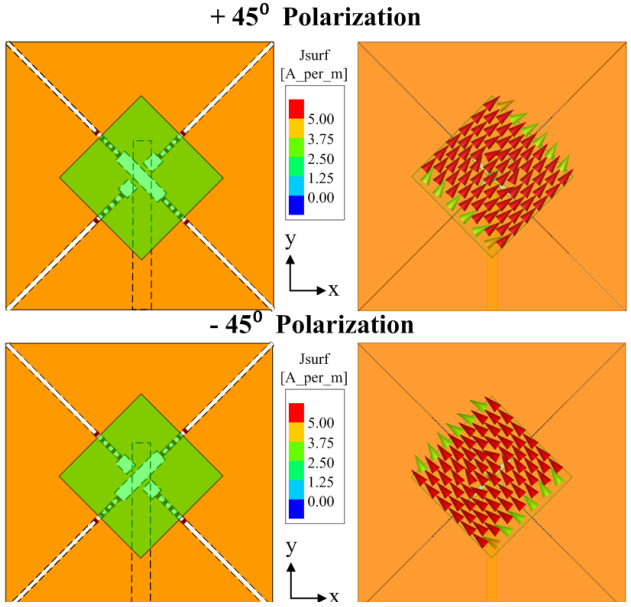


TABLE I

POLARIZATIONS BY DIFFERENT BIASING VOLTAGES

DC#1	DC#2	DC#3	DC#4	Polarization
1.5 V	0 V	0 V	1.5 V	+ 45°
0 V	0 V	1.5 V	1.5 V	- 45°

- Idea: To realize a reconfigurable aperture feeding structure for stacked square patches
- New method, simple, wideband

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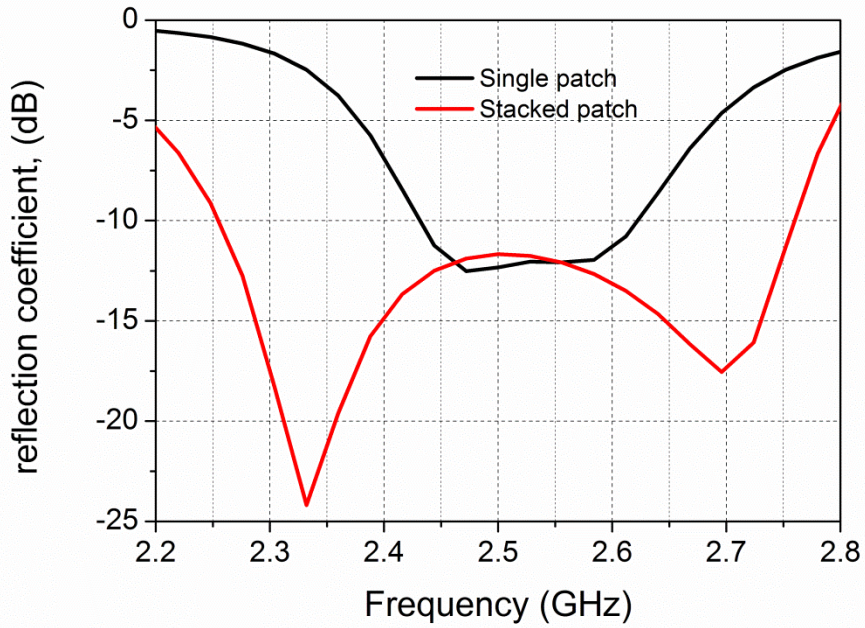
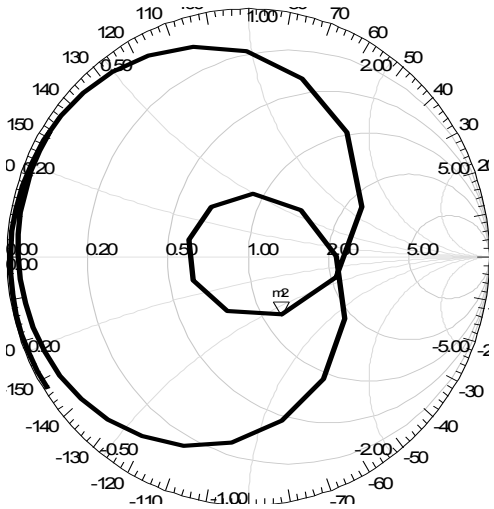
Bandwidth comparison between single patch and stacked patches

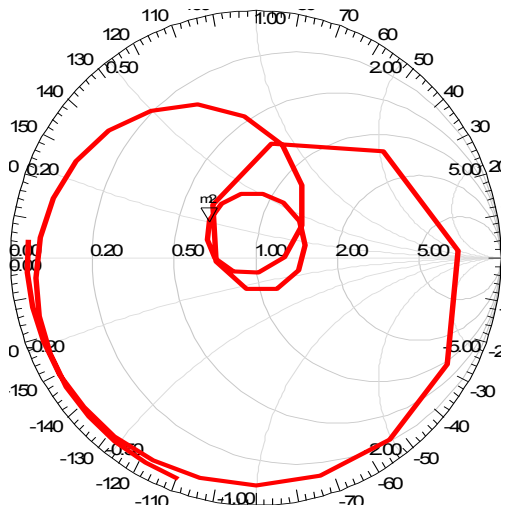
Reflection coefficient



Smith Chart



Single patch:
Single loop



Stacked patch:
Double loop

❖ **Stacked patches: To introduce an additional resonance to widen the bandwidth to 20% from 2.25 to 2.75 GHz**

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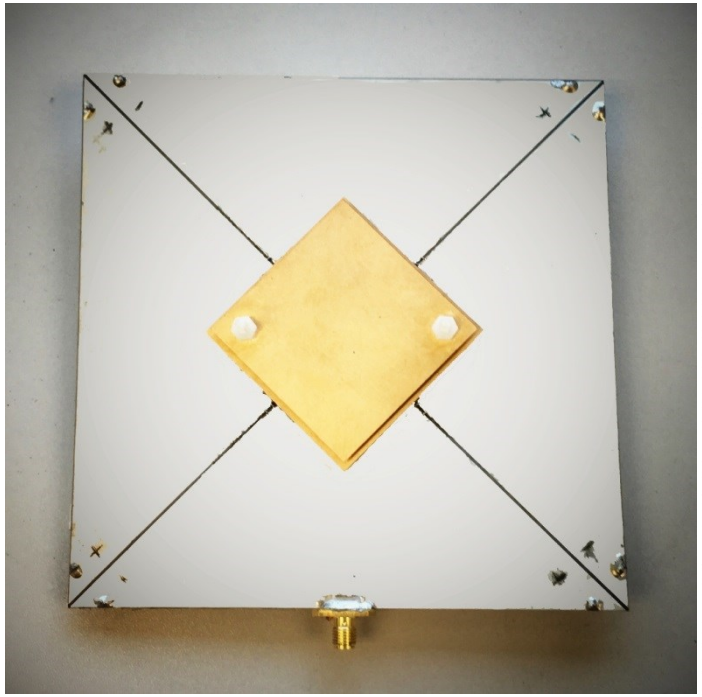
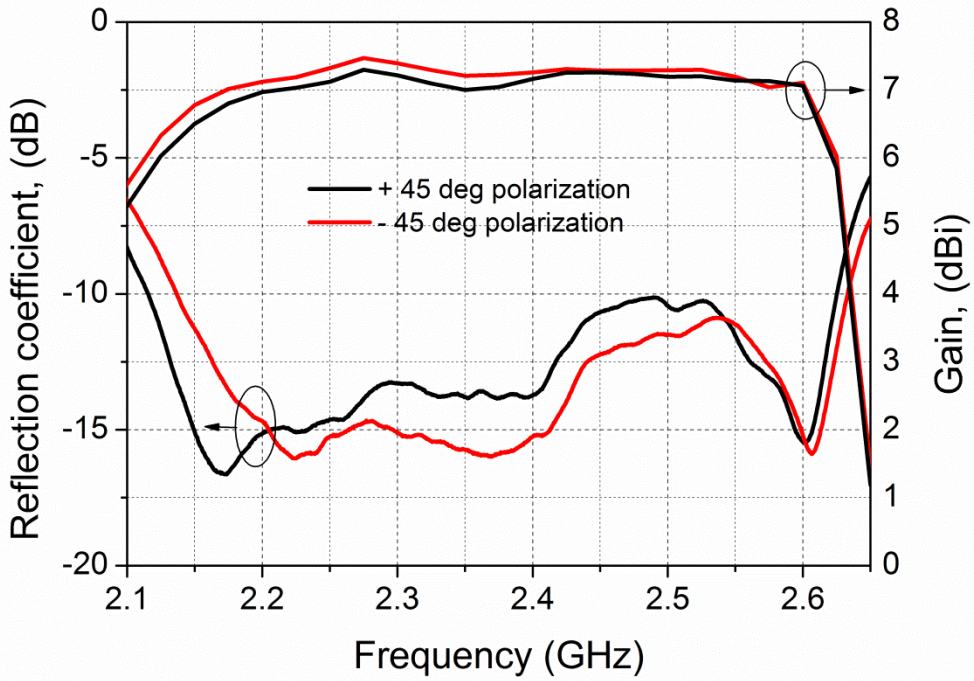
Measured results





- Measured overlapped impedance BW: 21% (0.5 GHz from 2.13 to 2.63 GHz)
- Gains are stable with the peak value of 7.5 dBi

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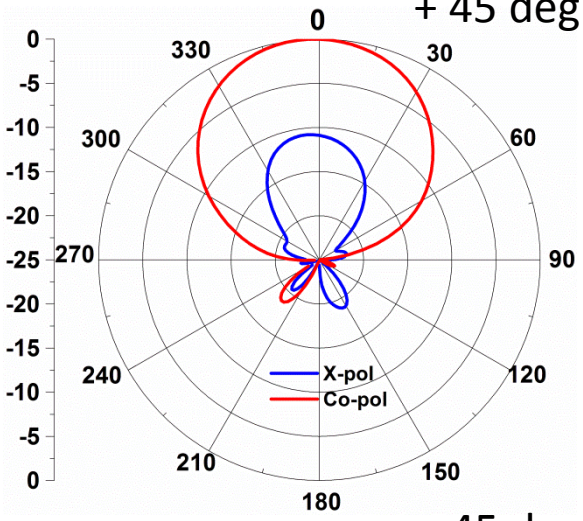
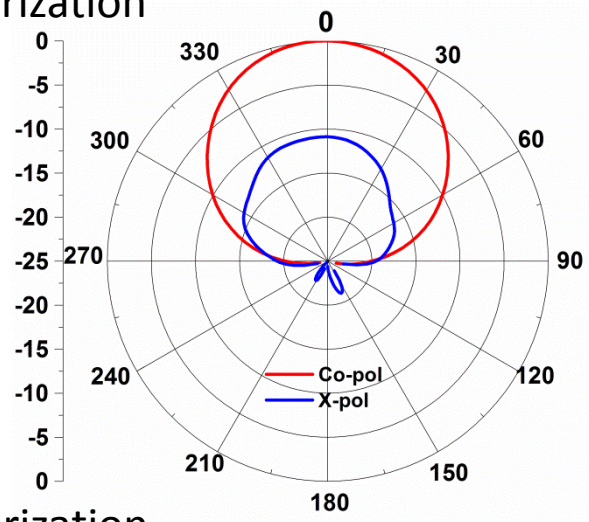
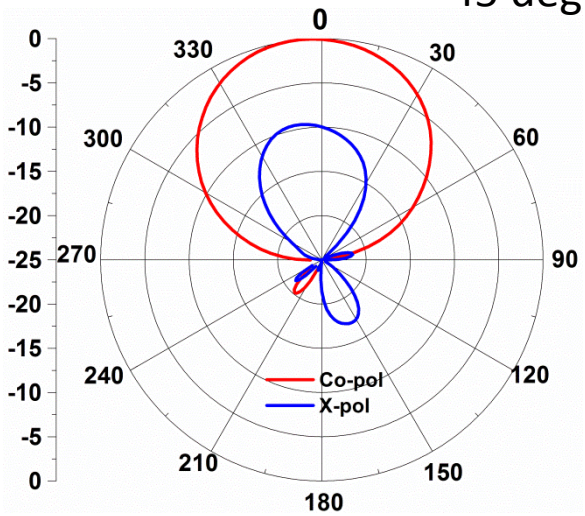
Measured radiation patterns

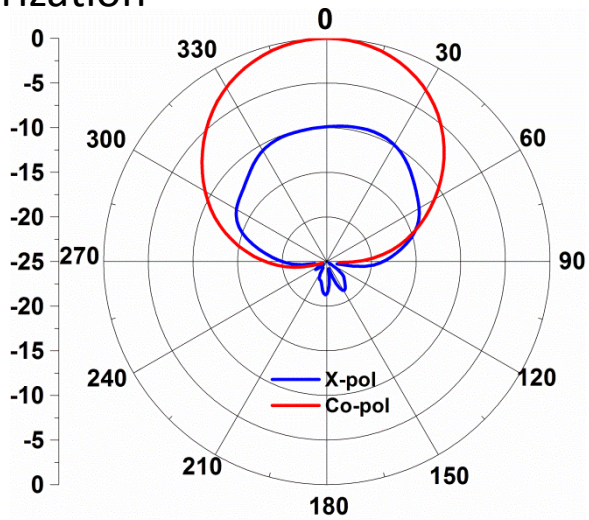
+ 45 deg polarization





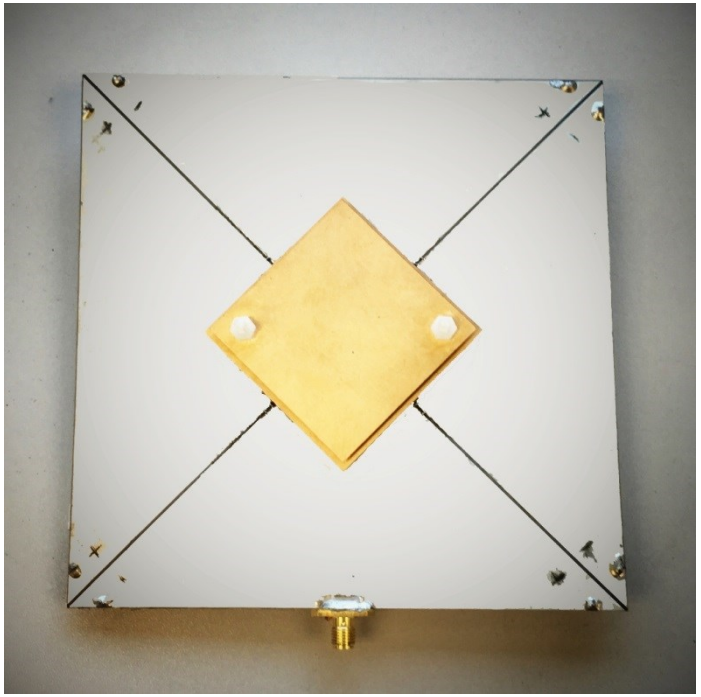
- 45 deg polarization

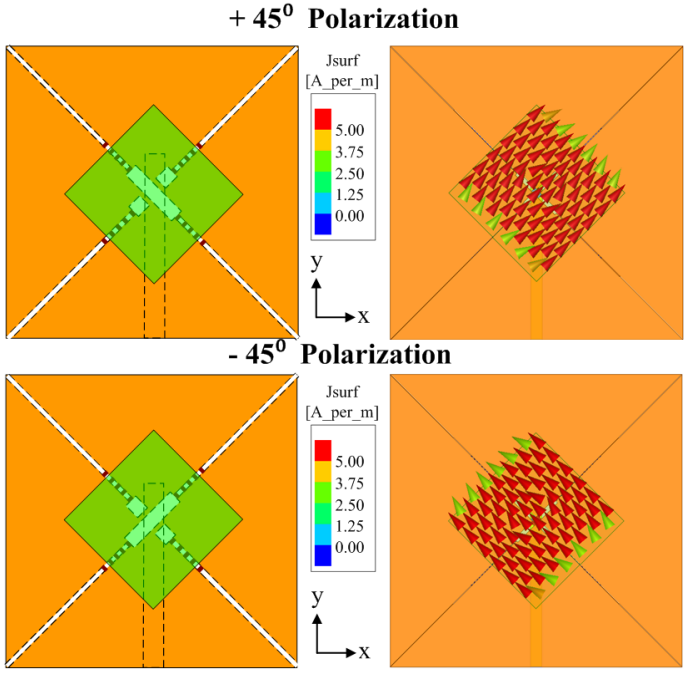




- Good broadside patterns (2.45 GHz) are obtained
- Cross polarization level is larger than 10 dB

Linear polarization reconfigurable





- ±45° wideband Linear Polarization Reconfigurable Antenna is realized
- How about wideband circular polarization reconfigurable antenna?

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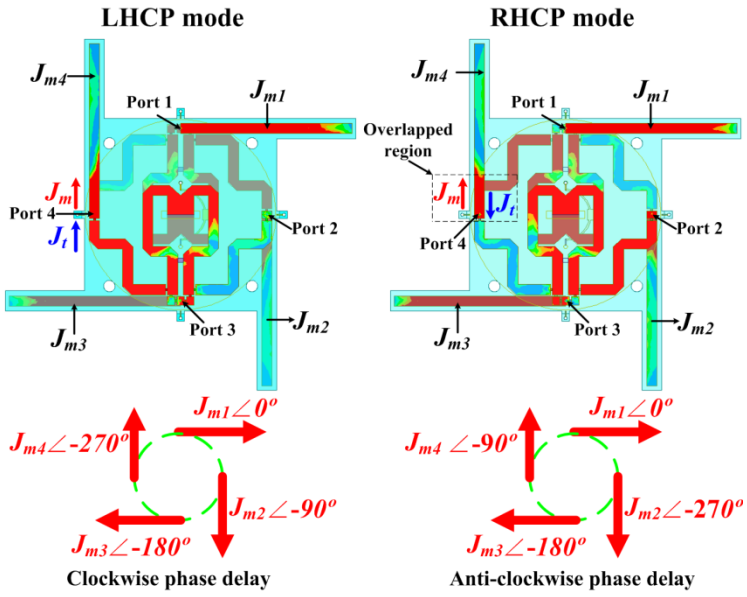
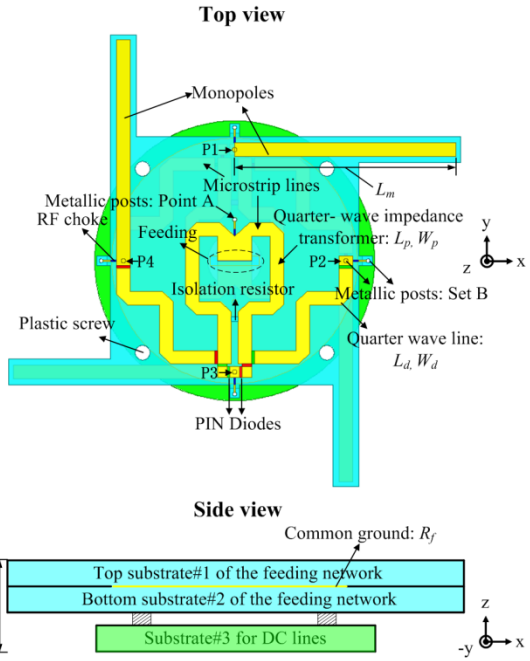
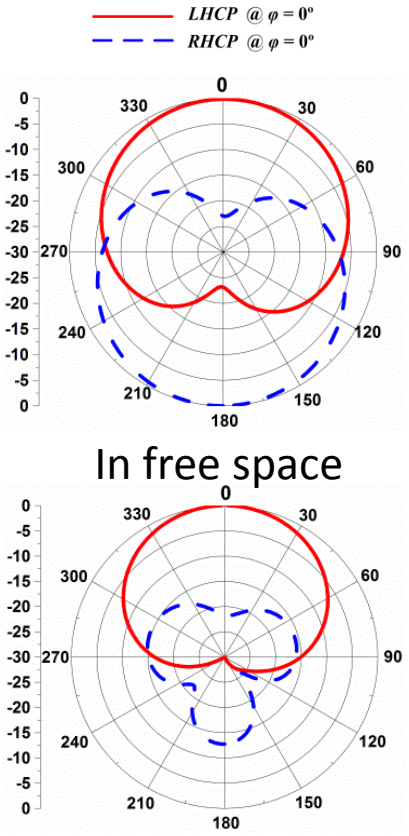
Wideband Circular Polarization Reconfigurable Antenna with Broadside Radiation Pattern







W. Lin and H. Wong, "Wideband circular polarization reconfigurable antenna," IEEE Trans. Antennas Propag., Accepted, Oct, 2015

- Idea: Sequentially-placed monopoles + output phase reconfigurable feeding network
- Similar to orthogonal dipoles + differential feed

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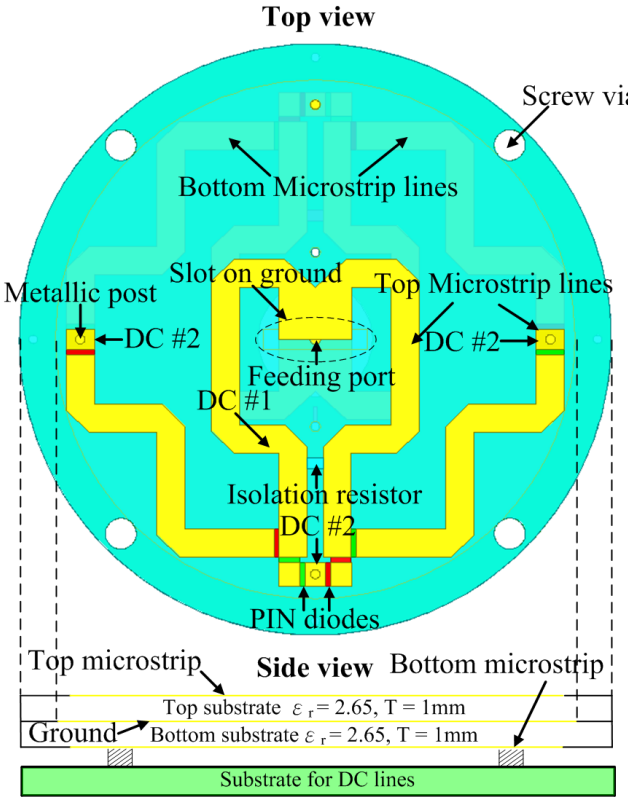
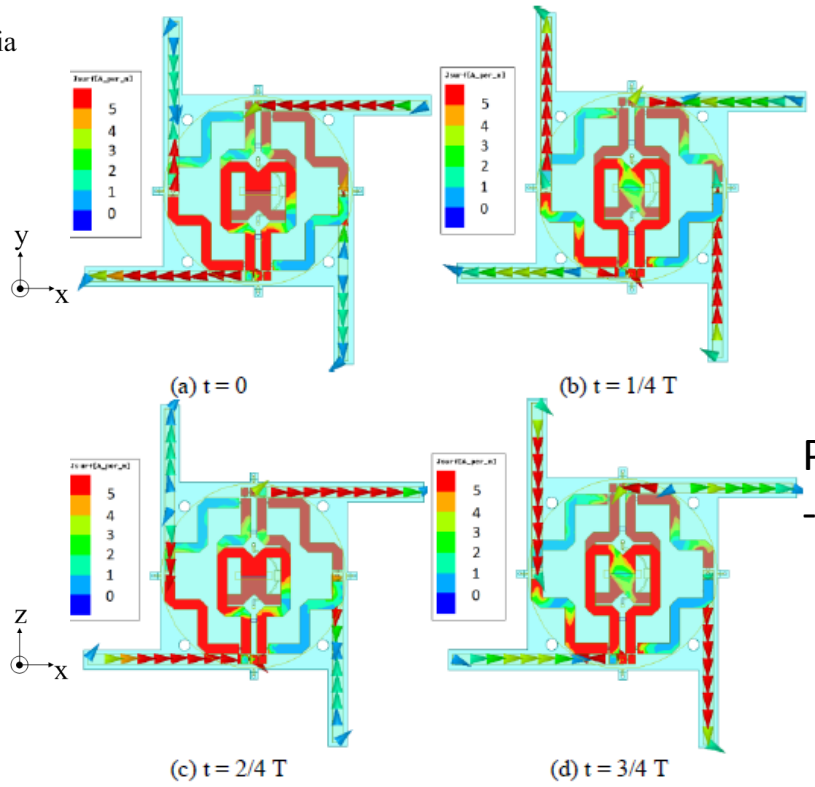
Operating principle



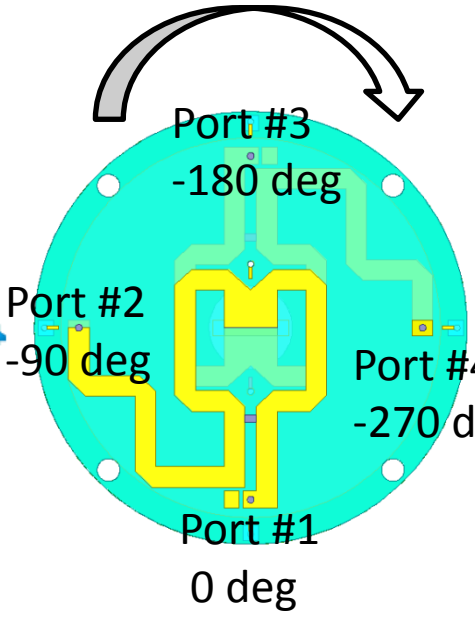
Output phase reconfigurable feeding network

Red diodes: ON and Green diodes: OFF



Current distribution within a period

Clockwise phase delay



- **Clockwise phase delay: LHCP in broadside**
- **Anti-clockwise phase delay: RHCP in broadside**

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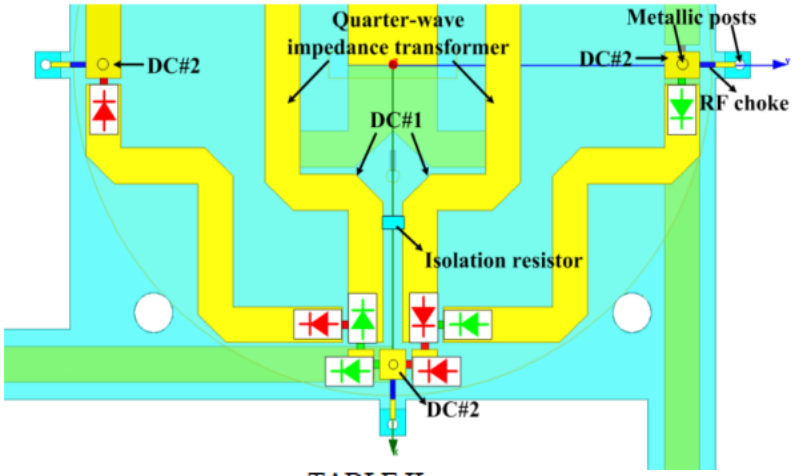
Diodes implementation



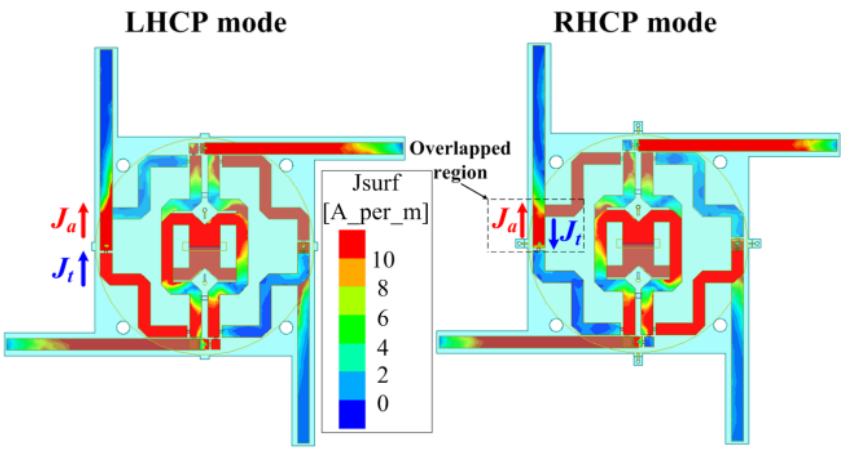
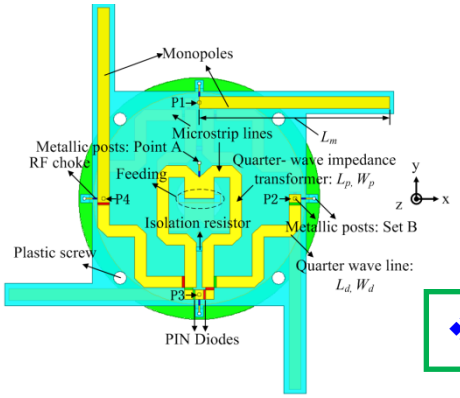
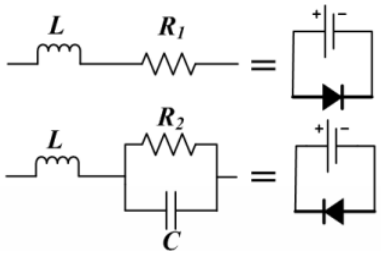


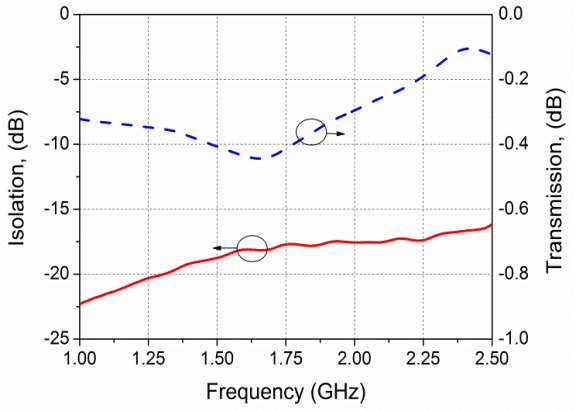
TABLE II
POLARIZATIONS BY DIFFERENT STATUS OF PIN DIODES

DC#1	DC#2	Red (dark) diodes	Green (light) diodes	Polarization
3 V	0 V	ON	OFF	LHCP
0 V	3 V	OFF	ON	RHCP

Diode characteristics- Bar50-02L from Infineon Technologies







❖ **CP radiations are switchable by two DC biases**

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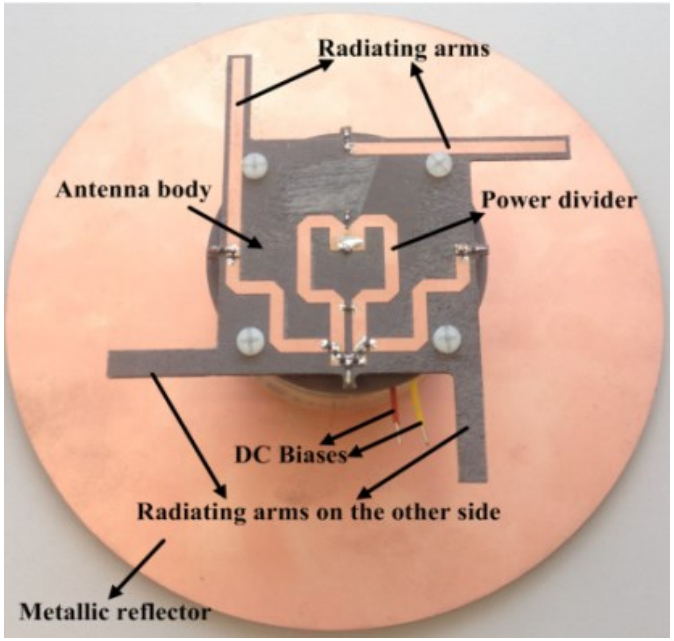
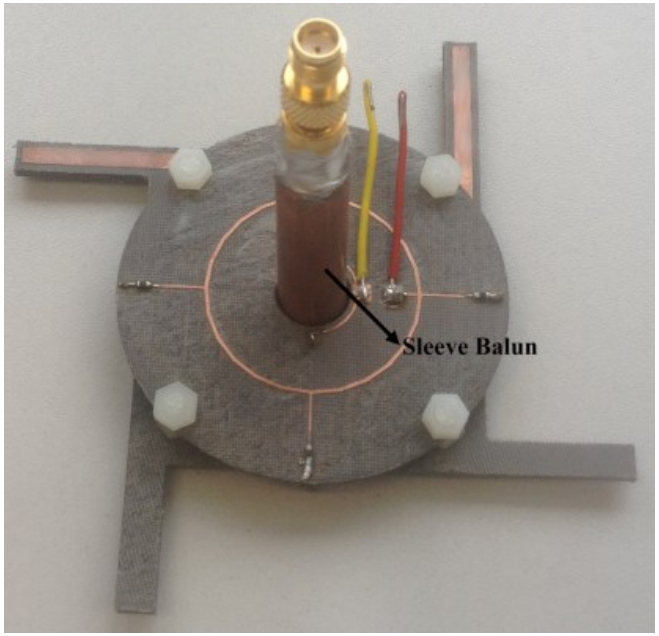
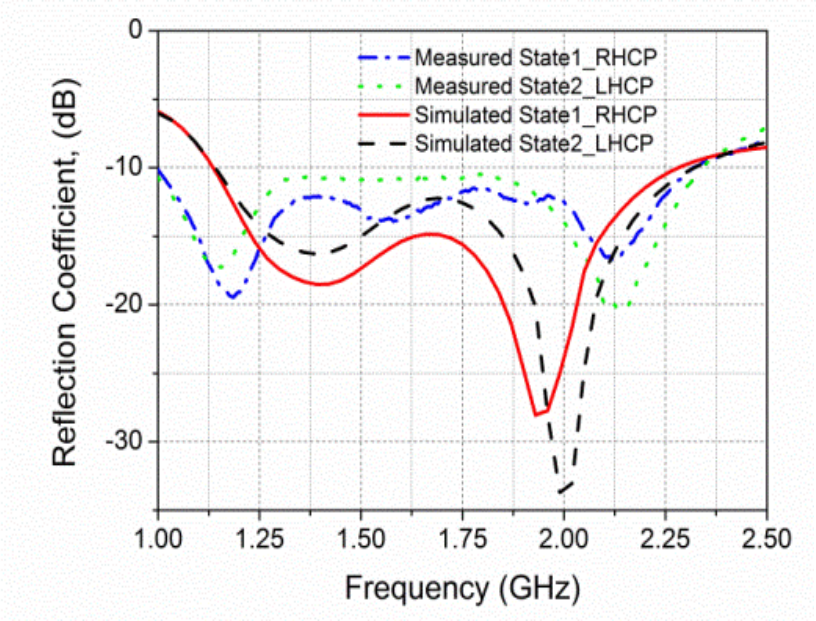
Fabricated antenna

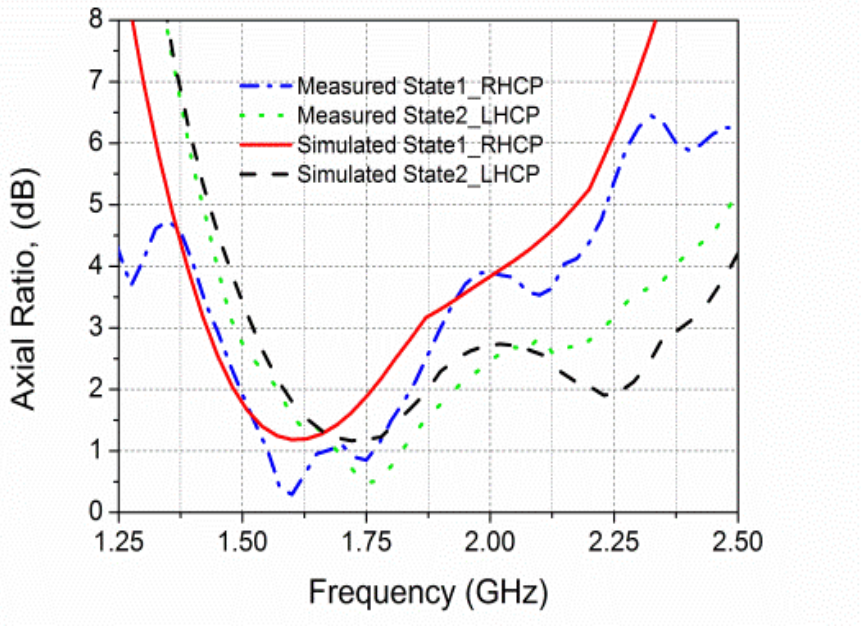




- Compact configuration with balun
- Another substrate below for DC lines

Measured impedance & AR bandwidth





- **10-dB impedance bandwidth: 80% from 1 to 2.35 GHz**
- **AR bandwidth: LHCP mode (37.8% from 1.5 to 2.2 GHz), RHCP mode (26.9% from 1.45 to 1.9 GHz), Overlapped (23.5% from 1.5 to 1.9 GHz).**

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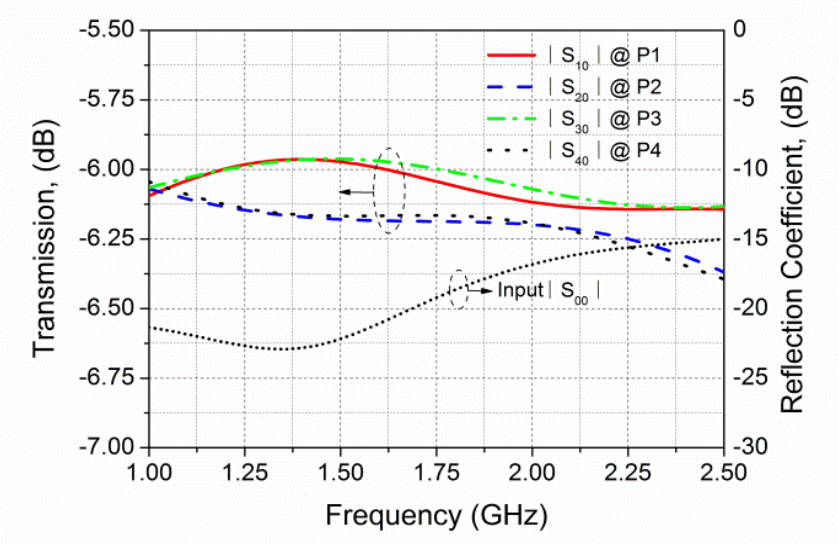
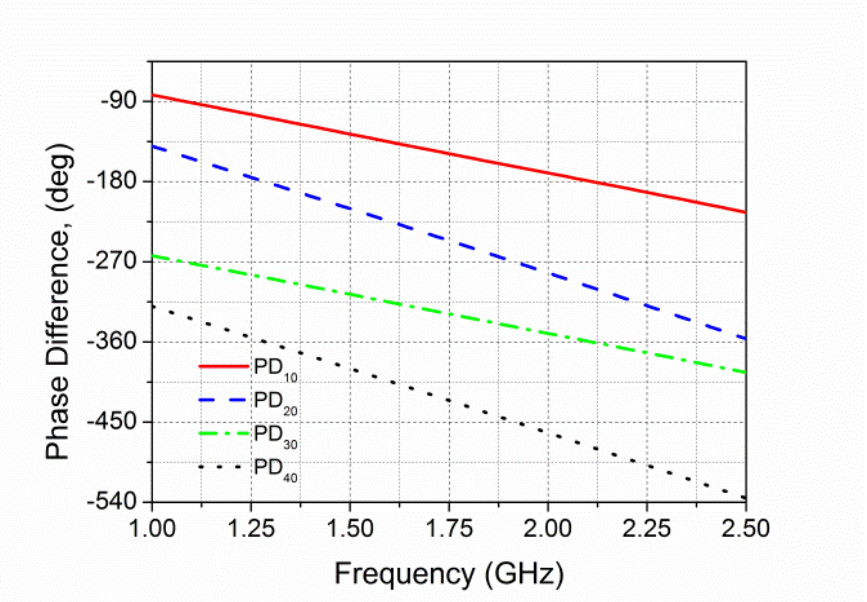
Characteristics of the feeding network



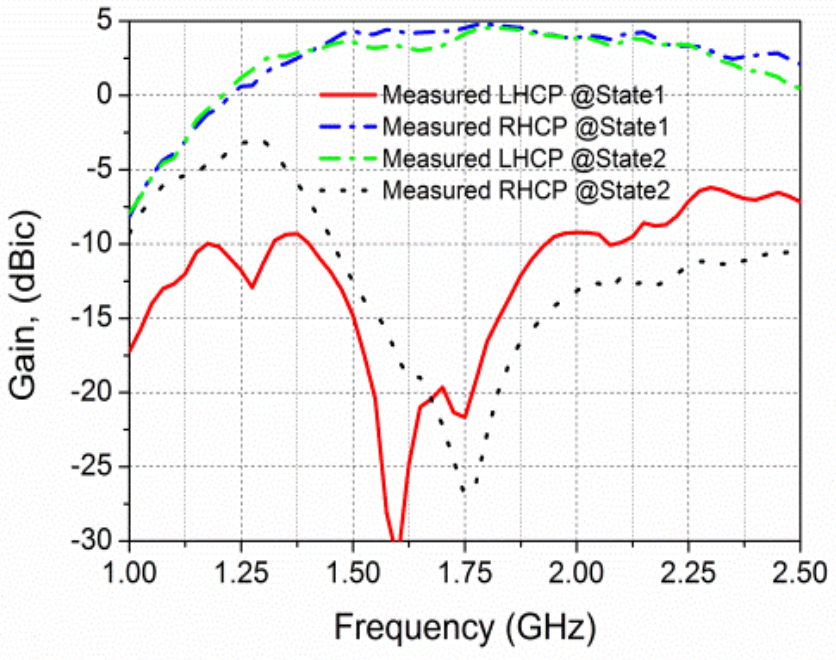
Amplitude response

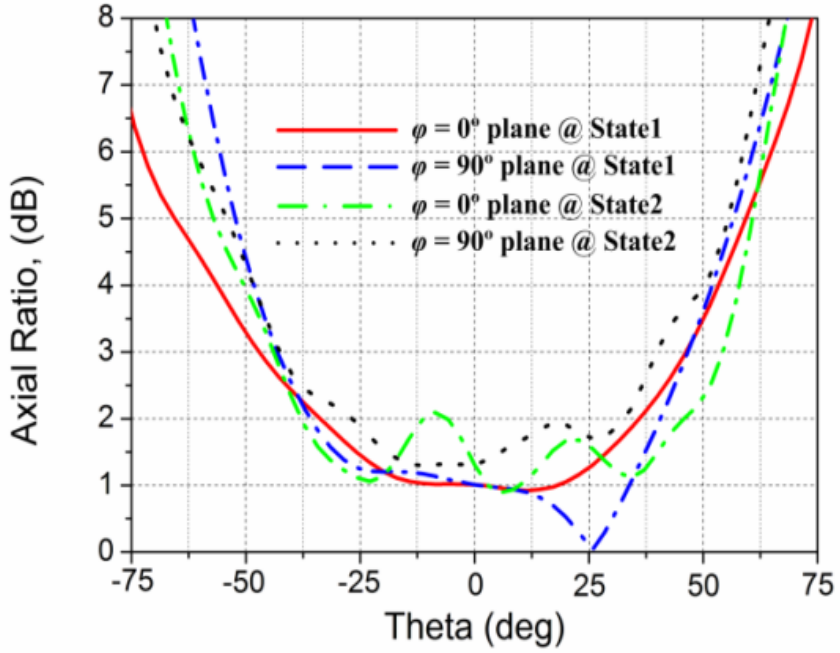


Phase response

❖ **Wideband performance is from the wideband output response of the feeding network**

Measured gain and AR beamwidth





- Gain: stable with peak value of 4.8 dBic
- AR Beamwidth: larger than 90 degree

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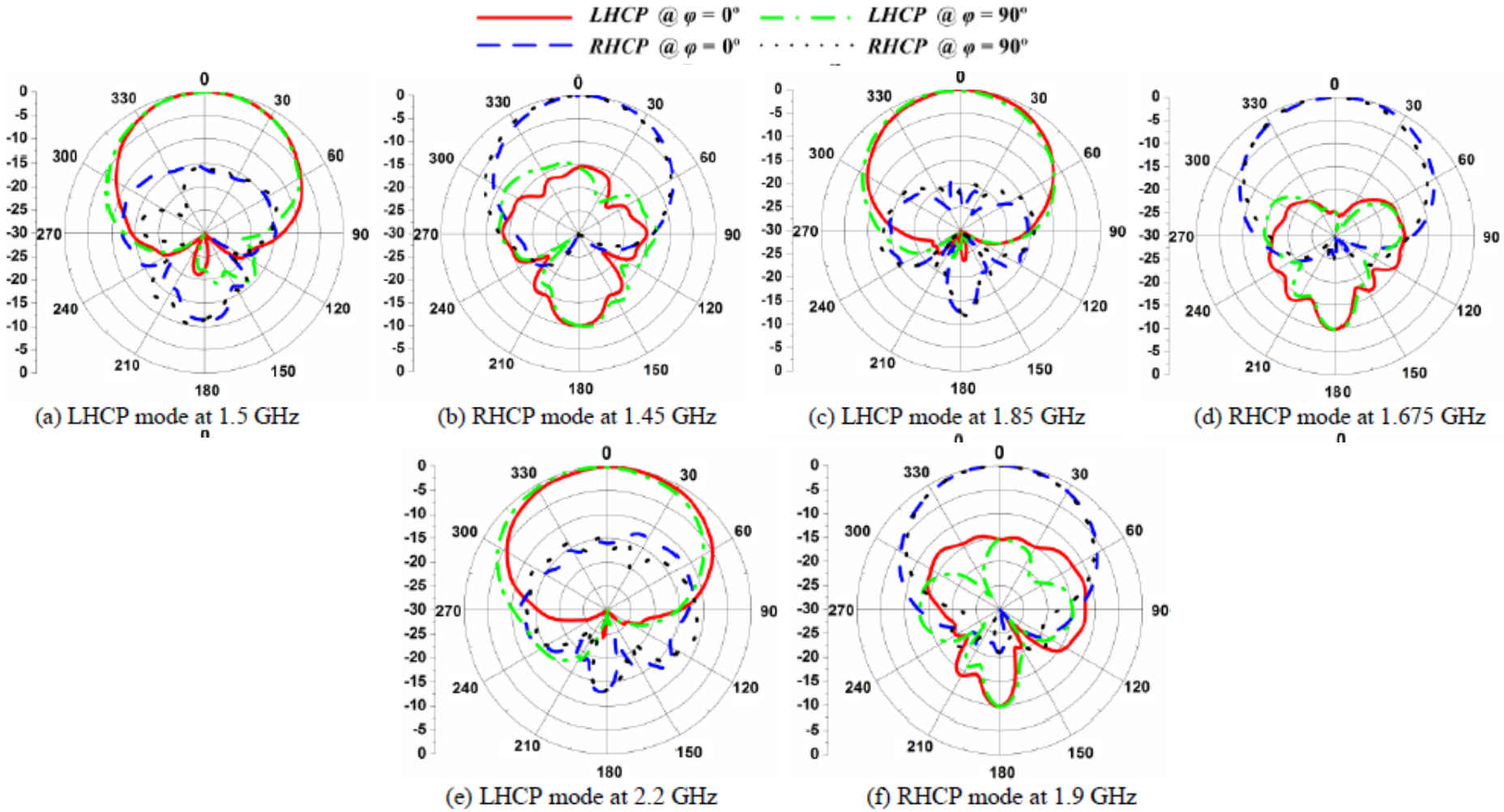
Measured radiation patterns



(a) LHCP mode at 1.5 GHz

(b) RHCP mode at 1.45 GHz

(c) LHCP mode at 1.85 GHz

(d) RHCP mode at 1.675 GHz

(e) LHCP mode at 2.2 GHz

(f) RHCP mode at 1.9 GHz

❖ **Radiation pattern: good broadside pattern and stable across the operating bandwidth**

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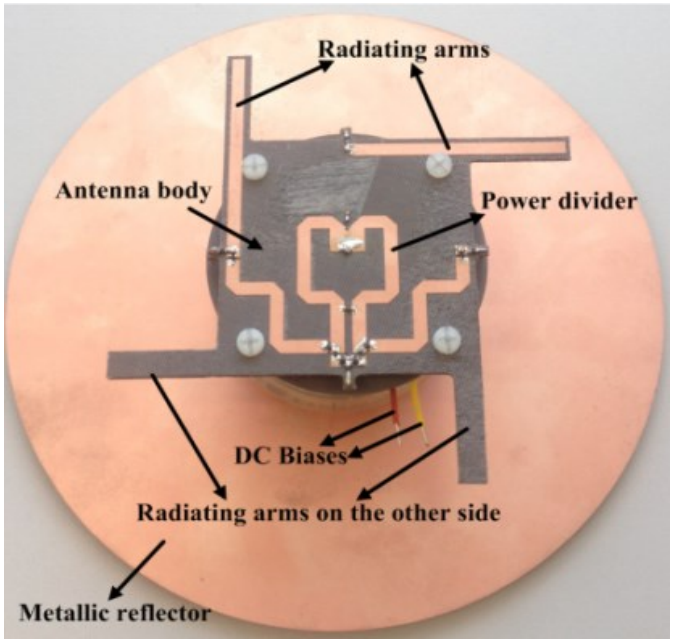
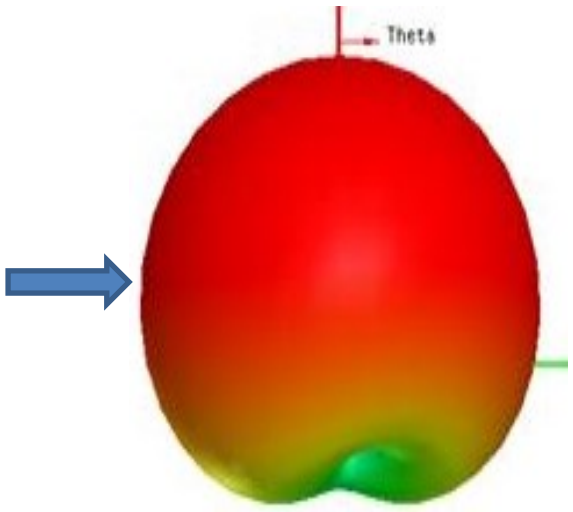
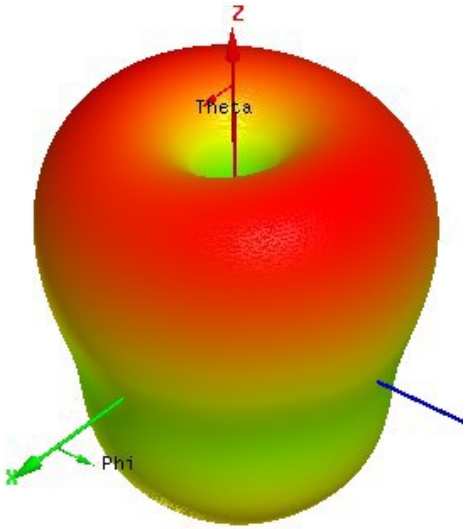
Broadside and conical-beam patterns





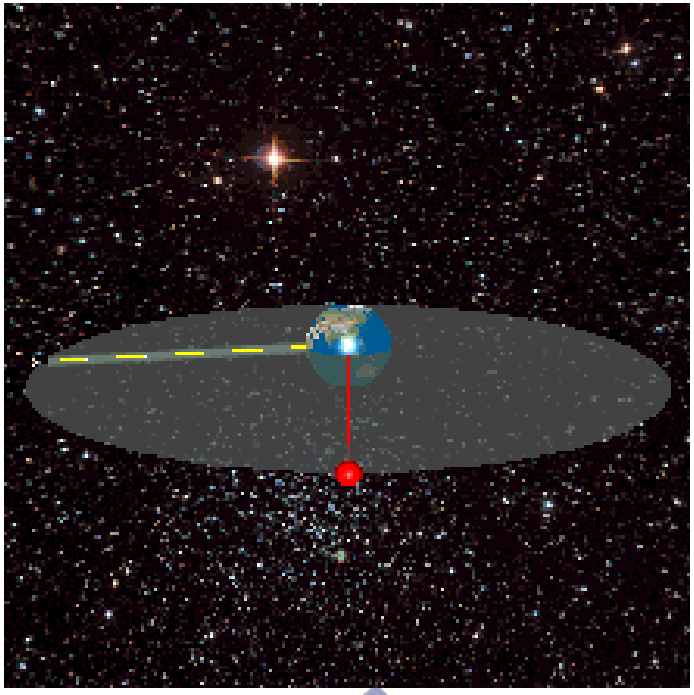
Broadside pattern

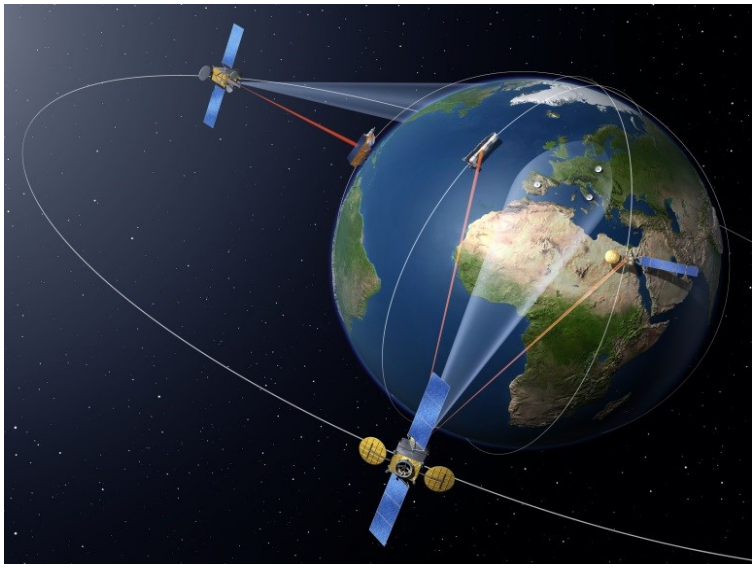


Conical-beam pattern

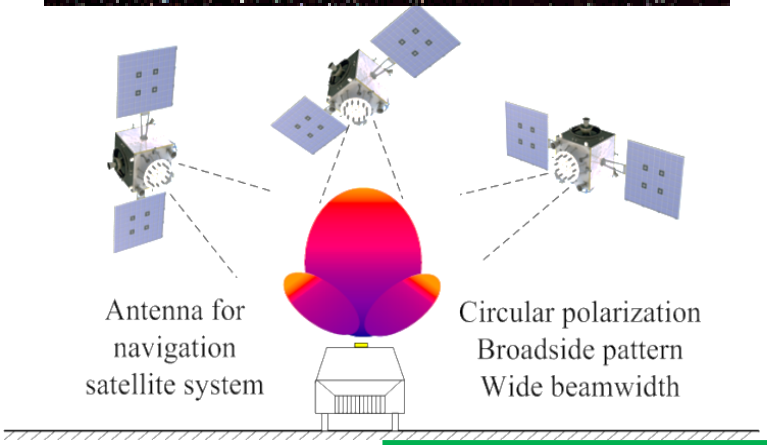
❖ Different applications require different patterns

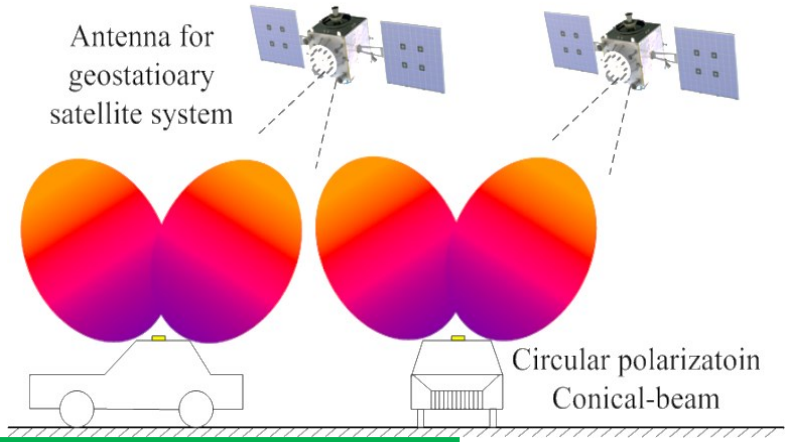
Satellite communication systems





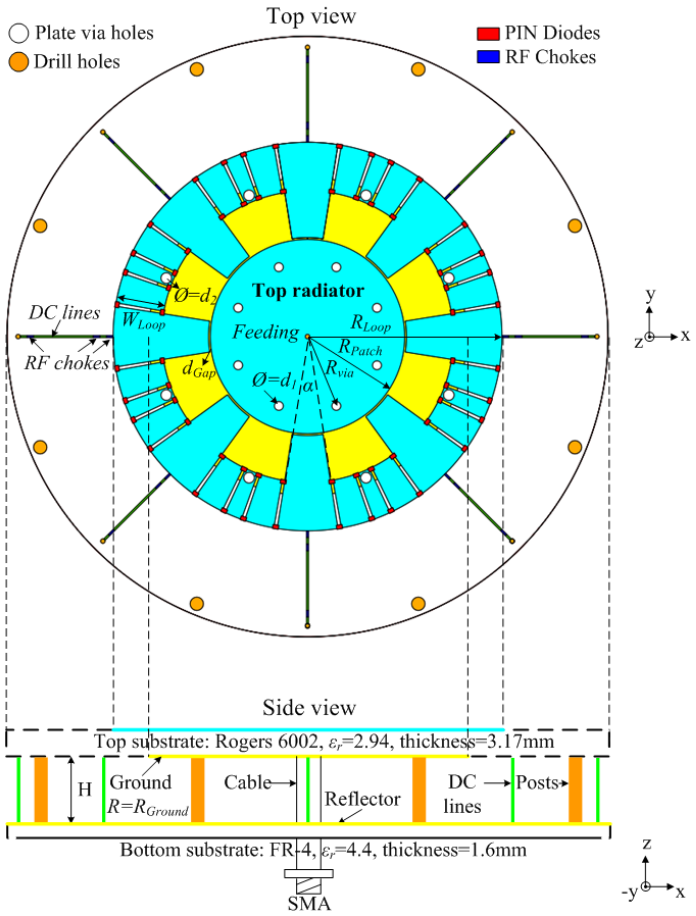
Geostationary satellite system

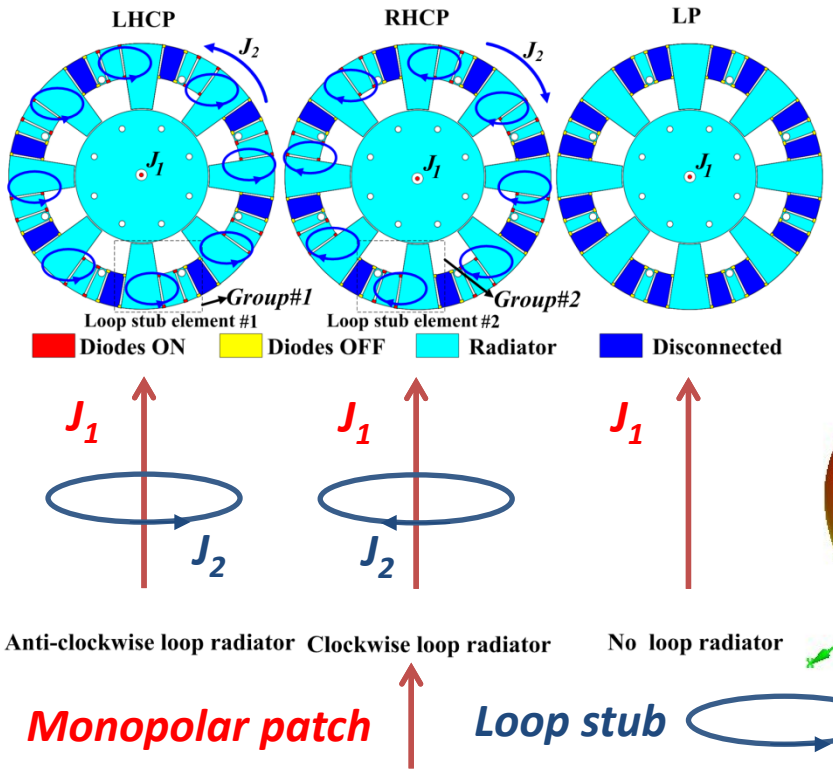


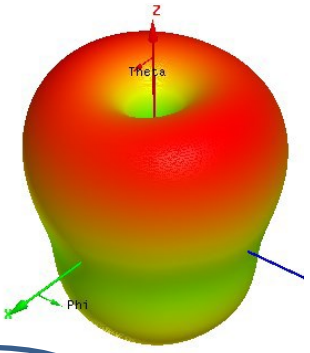


- GPS, “Bei dou”, Galileo, GLONASS
- TV broadcasting, weather forecast, imaging, data relay and satellite phone

Wideband Polarization Reconfigurable Antenna with Conical-beam Radiation Pattern







W. Lin and H. Wong, "Polarization reconfigurable wheel-shaped antenna with conical-beam radiation pattern," IEEE Trans. Antennas Propag., vol. 63, no. 2, pp. 491–499, Feb, 2015

- Wideband monopolar patch + end-shorted loop stub = wideband CP with conical-beam
- LHCP or RHCP is determined by loop direction

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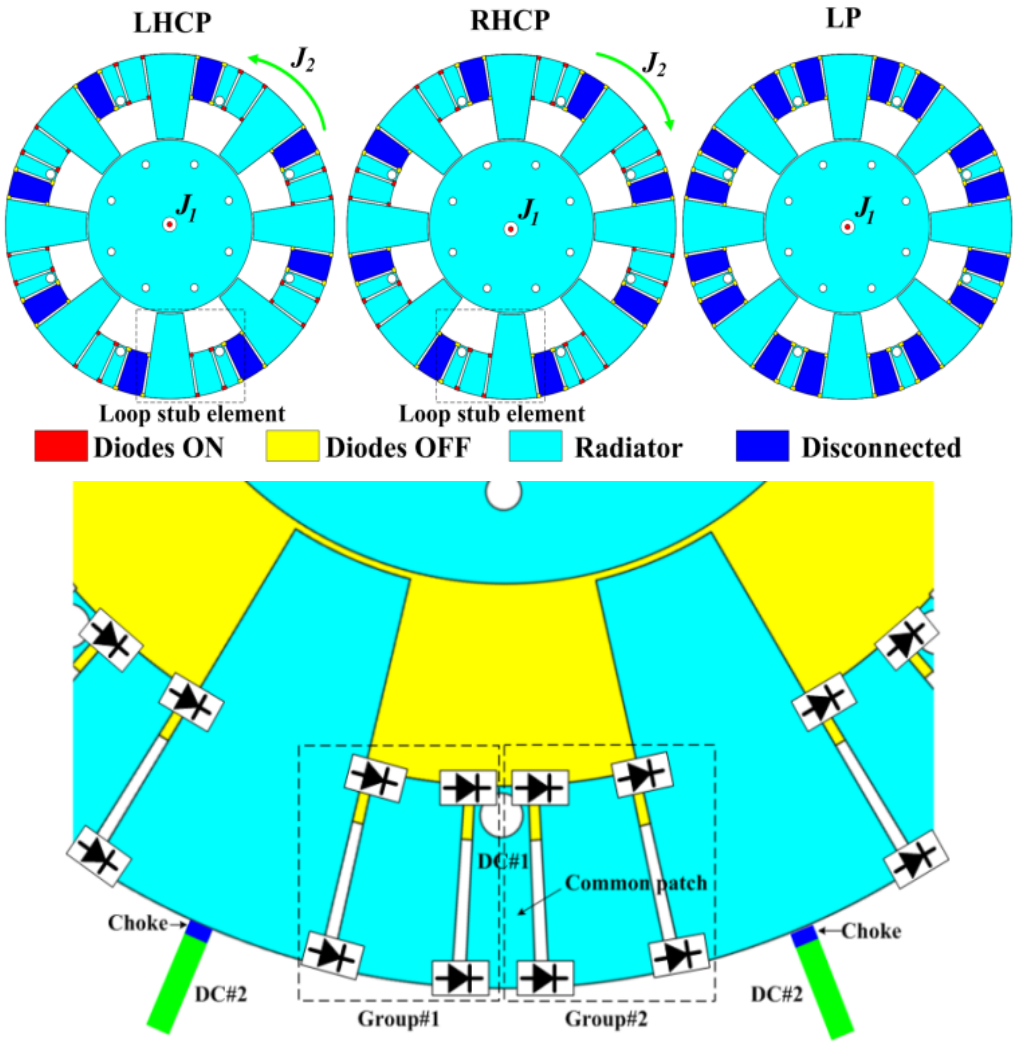
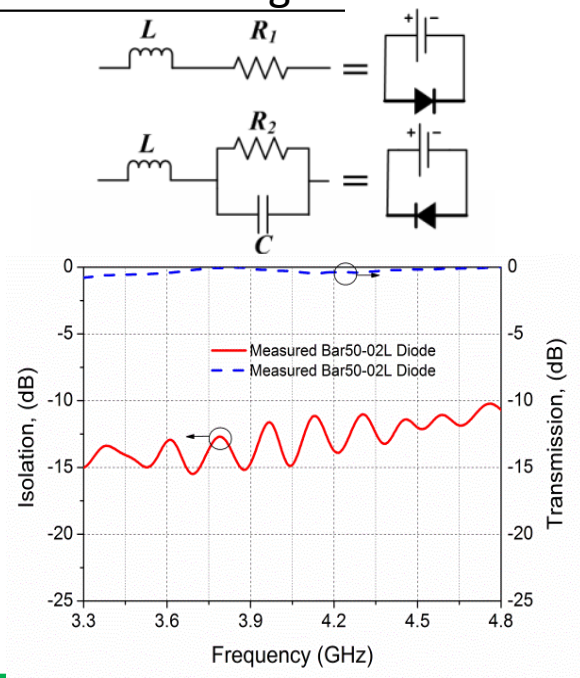
Operating principle



Polarization control scheme

DC#1	DC#2	Group#1	Group#2	Polarization
0 V	3 V	ON	OFF	LHCP
3 V	0 V	OFF	ON	RHCP
0 V	0 V	OFF	OFF	LP

Diode characteristics- Bar50-02L from Infineon Technologies



❖ **RHCP, LHCP and LP can be controlled by different DC bias**

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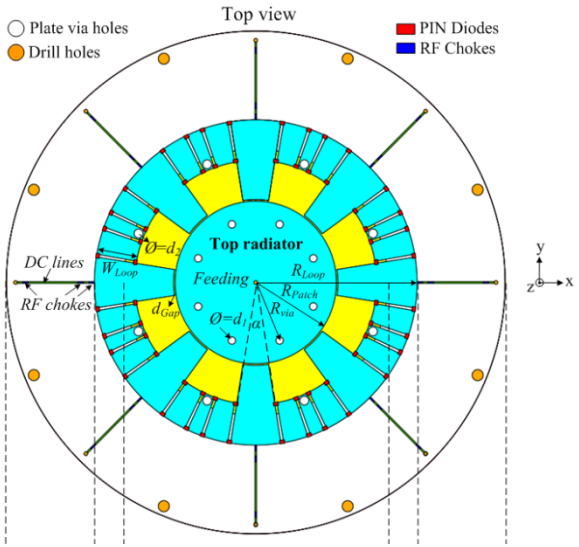
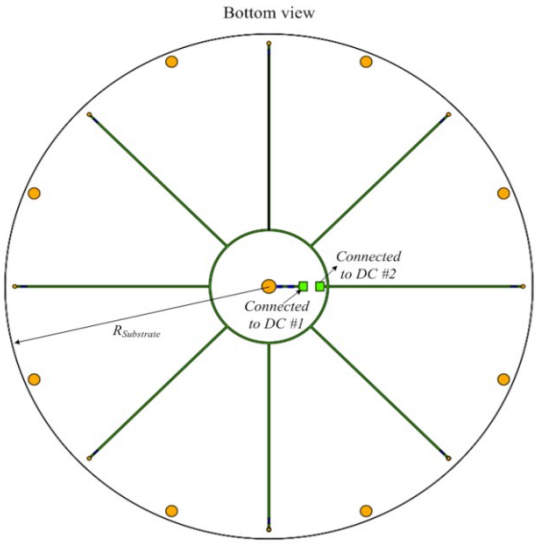
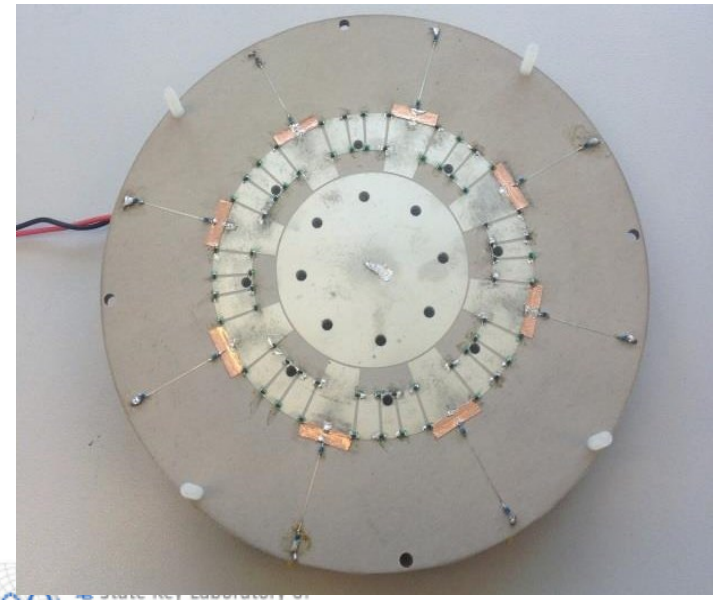
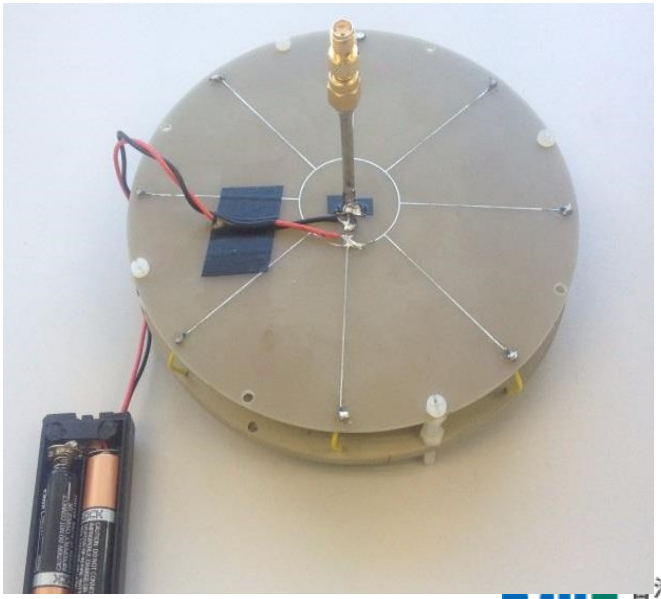
Full Model with DC Biasing Lines



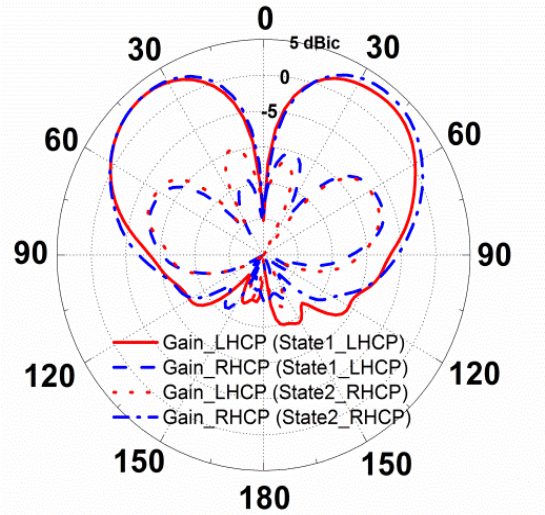




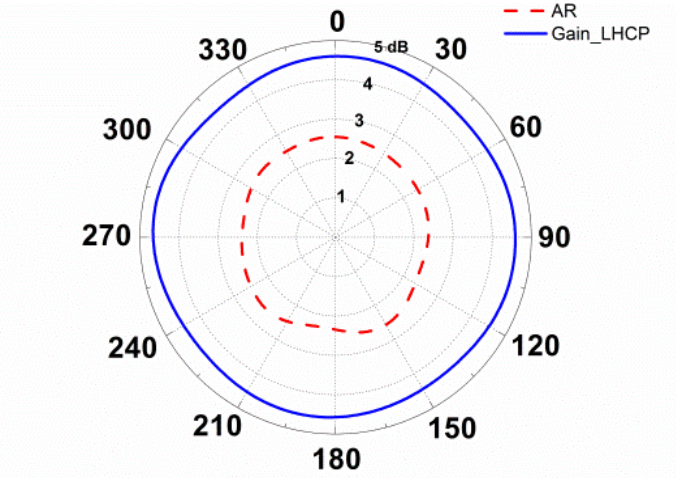


❖ **Copper paper patches for tuning**

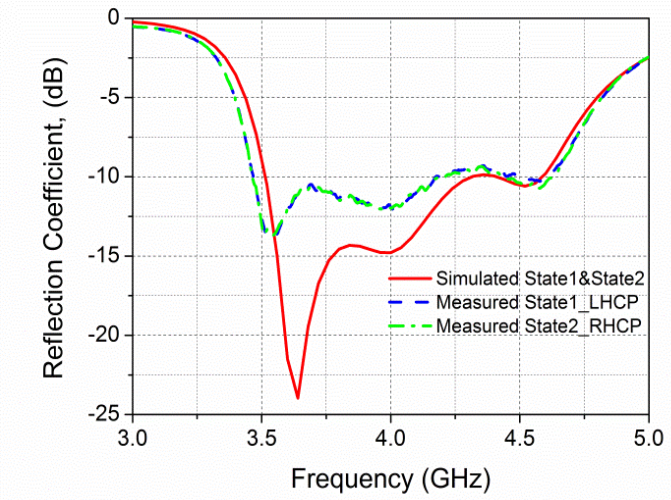
Measured Results

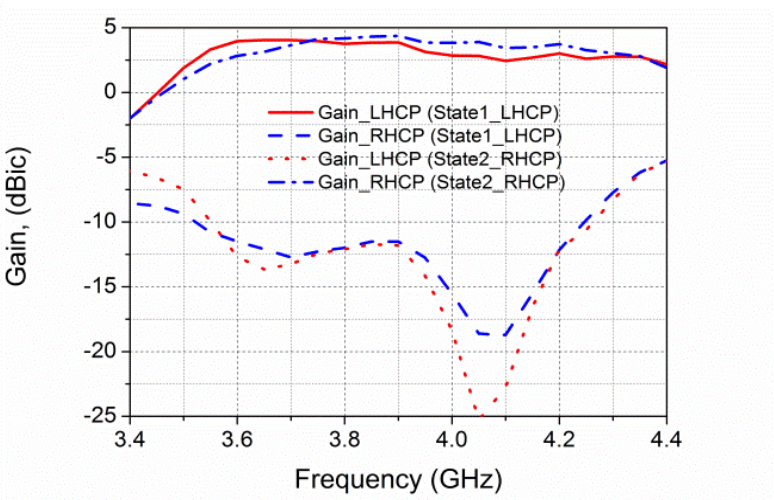


Radiation Pattern at 4 GHz



Gain and AR values at the azimuth plane





- Impedance BW = 28.6% (3.45 to 4.6 GHz)
- AR BW = 15.4% (3.6 to 4.2 GHz)

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Performance comparison

- New low-profile conical-beam CP antenna has been introduced.
- Combined the vertical polarization of the patch and horizontal polarization of parasitic loop stubs.
- The proposed antenna can transfer to a polarization reconfigurable antenna.
- Both antennas have wideband CP conical-beam patterns which could be applied to geostationary satellite communications.

TABLE I
PERFORMANCE COMPARISON OF CP CONICAL BEAM ANTENNAS

Type of conical beam CP antennas	Center frequency	AR bandwidth	Profile (x × y × z)	Max. Gain	Network Required	Fabrication Complexity
Patch [1]	2.295 GHz	4%	0.9 λ × 0.9 λ × 0.19 λ	6.9 dBic	Yes	Medium
Monopole [4]	1.618 GHz	2.8%	0.43 λ × 0.43 λ × 0.45 λ	4.5 dBic	Yes	Medium
Dipole [3]	4.5 GHz	3%	unknown × unknown × 0.47 λ	0.6 dBic	No	Simple
Loop [7]	1.5 GHz	0.5%	unknown × unknown × 0.064 λ	0.7 dBic	Yes	Simple
Folded loop stubs [8-9]	2.3385 GHz	< 2%	0.72 λ × 0.72 λ × 0.07 λ	2.2 dBic	No	Simple
Waveguide [5]	12.5 GHz	4.8%	3.2 λ × 3.2 λ × 1 λ	7.5 dBic	Yes	Complex
Monopole + Polarizer [10]	5.3 GHz	54.9%	0.9 λ × 0.9λ × 0.43 λ	6.3 dBic	No	Complex
Patch + Feeding network [11]	2.53 GHz	28.3%	2.6 λ × 2.6 λ × 0.084 λ	5.5 dBic	Yes	Complex
Proposed Antenna	6.25 GHz	14.4%	1.16 λ × 1.16 λ × 0.06 λ	4.9 dBic	No	Simplest
Proposed Reconfig. Ant.	4 GHz	15.4%	1.16 λ × 1.16 λ × 0.25 λ	4.4 dBic	No	Simple

- **Wideband as CP conical-beam antenna**
- **First design to achieve CP reconfigurable antenna with conical-beam pattern**

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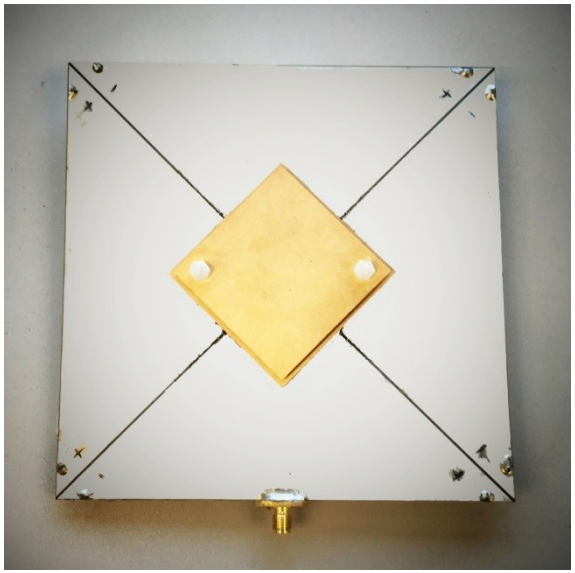
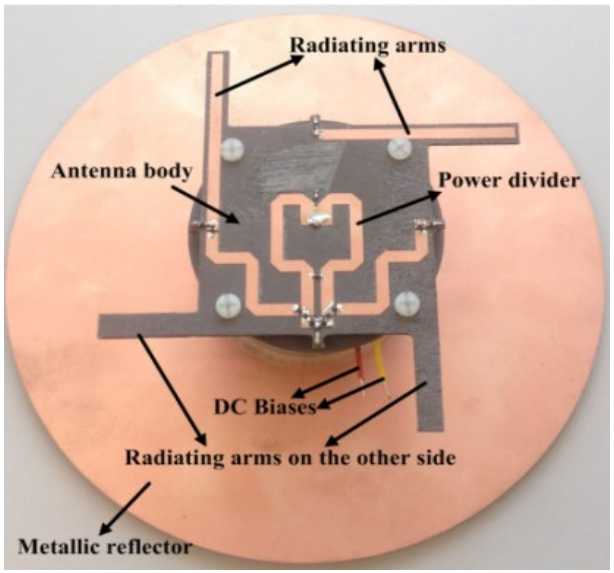
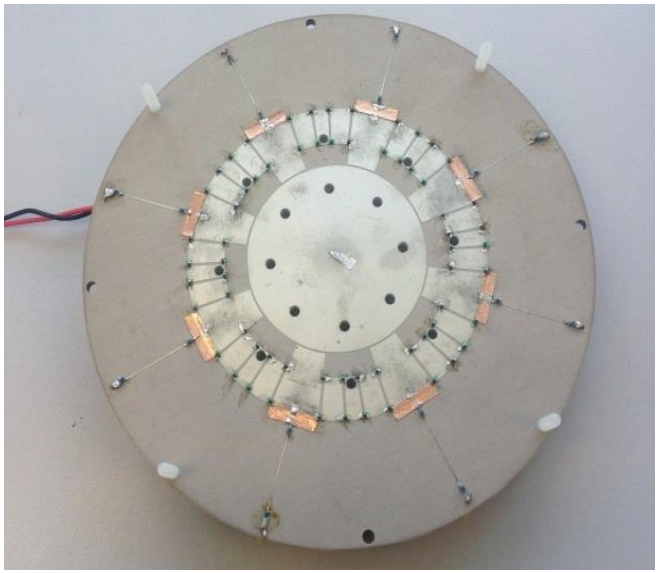
Conclusion



Wideband ±45^o Linear Polarization Reconfigurable Antenna with Broadside Radiation Pattern



Wideband CP reconfigurable antenna with broadside pattern



Wideband CP reconfigurable antenna with conical-beam pattern

- **Provide new designs for realizing specific reconfigurable radiations**
- **Overcome the critical problem of narrow bandwidth in reconfigurable antenna designs**

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Thank you!

Q&A